# Effects of Scots Pine Sawdust on Quality, Growth, Photosynthetic Characteristics, and Nutrient Contents of *Lavandula officinalis*

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This study aimed to evaluate the effects of Scots pine (*Pinus sylvestris* L.) sawdust on the growth, aesthetic quality, photosynthetic pigments, and nutrient uptake of *Lavandula officinalis*, a widely cultivated medicinal and ornamental plant in Türkiye. Eleven growth media were formulated by mixing peat and perlite with sawdust at concentrations ranging from 5% to 50% (v/v). The results demonstrated that the 25% sawdust treatment significantly enhanced plant height, crown width, fresh weight, and visual appearance. Photosynthetic pigment concentrations (chlorophyll a, b, and carotenoids) were also optimized at this level, while higher sawdust proportions (≥ 40%) led to notable declines. Contrary to expectations, total nitrogen content increased with sawdust levels, possibly due to nitrogen-rich tissues in the sawdust and enhanced microbial mineralization. Calcium content peaked at 25%, whereas micronutrients such as iron, copper, and zinc decreased with higher sawdust ratios. The findings suggest that Scots pine sawdust, when applied at moderate levels, can serve as a sustainable substrate component in lavender cultivation. This is the first study to systematically assess Scots pine sawdust in lavender growing media, contributing to the development of resource-efficient and environmentally friendly horticultural practices.

*DOI: 10.15376/biores.20.3.5801-5813*

*Keywords: Plant nutrition; Chlorophyll content; Lavandin; Growth medium; Ornamental plant*

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## INTRODUCTION

The selection of appropriate growth media for plants stands as a critical factor in the realm of horticulture and agriculture. Producers are increasingly focused on identifying media that not only foster optimal plant growth but also align with economic sustainability (Çiçek and Yücedağ 2021). Among the available options, peat has historically been the predominant choice due to its beneficial properties. However, it is important to note that peat is derived from non-renewable sources, raising concerns about their long-term viability and environmental impact. Consequently, there is a growing global initiative to explore alternative growing media that can replace peat without compromising plant health (Dede *et al.* 2010).

One promising approach in this research involves the utilization of plant waste materials as organic components for growth media (Çiçek *et al.* 2021). These organic materials play a pivotal role in enhancing the physical, chemical, and biological properties of soils, thereby significantly promoting plant growth and health (Subpiramaniyam *et al.* 2021). For instance, materials such as sawdust contribute to improving soil structure and enhancing aeration, which are essential for root respiration and nutrient uptake. Additionally, these organic amendments increase the organic matter content of the soil, fostering a more robust microbial ecosystem that further supports plant vitality. Importantly, using such organic materials has the advantage of maintaining soil pH at desirable levels. Unlike traditional composts that often lead to elevated pH levels, which can be detrimental to certain plant species, sawdust and similar materials help stabilize pH, ensuring that it remains conducive to plant growth (Davis and Strik 2022). This multifaceted approach to growing media not only supports sustainable agricultural practices but also aligns with the increasing demand for environmentally friendly solutions in plant cultivation.

Sawdust, which is composed of minuscule particles generated as a byproduct in various industries such as sawmilling, pulp and paper production, and wood processing, represents a significant yet often overlooked resource in agricultural and environmental management (Abiodun *et al.* 2022; Eifediyi *et al.* 2022). When incorporated into soil, sawdust can play a pivotal role in fostering a slow-decomposing organic carbon pool. This process is crucial for climate change mitigation, as it effectively reduces greenhouse gas emissions by sequestering carbon in the soil (Ashiono *et al.* 2017). As sawdust undergoes decomposition, it transforms into humus, a rich organic material that gradually releases essential nutrients into the soil. This nutrient release is particularly beneficial for promoting healthy crop growth, enhancing soil fertility, and improving overall agricultural productivity (Azuka *et al.* 2024). Beyond its environmental advantages, sawdust serves as a cost-effective and sustainable solution for soil enhancement. Its use in agriculture not only improves soil structure and moisture retention, but it also contributes to the reduction of waste from industrial processes (Agboola *et al.* 2018; Khomami *et al.* 2021). In particular, the application of fresh sawdust in sandy soil can yield significant benefits, even when applied in its uncomposted state. However, to maximize its effectiveness, it is crucial to supplement this application with additional mineral nitrogen. This practice stimulates microbial activity, facilitating the decomposition of sawdust and ultimately supporting robust plant growth (Małecka and Kwasna 2015). Thus, the strategic use of sawdust in agricultural practices not only enriches the soil but also aligns with broader sustainability goals, making it a valuable asset in both farming and environmental stewardship.

The carbon-to-nitrogen (C:N) ratio plays a pivotal role in influencing microbial activity during the decomposition of organic materials, particularly when woody substrates like sawdust are utilized in growing mediums, as evidenced by research conducted by Huang *et al.* (2004). It is widely acknowledged that sawdust, characterized by a high C:N ratio, can lead to nitrogen immobilization, which poses a significant risk of nutritional deficiencies, especially in young seedlings that are particularly sensitive to nutrient availability. This phenomenon underscores the importance of managing nutrient ratios in soil amendments to ensure optimal growth conditions for seedlings (Huang *et al.* 2004).

Despite its potential drawbacks, sawdust's slow decomposition process can serve as a valuable source of long-term organic matter for plants (Rajor *et al.* 1996). When appropriately mixed with other substrates such as perlite and peat, and under optimal aeration conditions, sawdust can significantly enhance soil structure (Olayinka and Adebayo 1985). This careful balancing act is essential for maximizing plant growth while simultaneously minimizing nitrogen loss in agricultural practices. This is especially critical in arable soils amended with cellulose-rich materials including sawdust, where the interplay between carbon and nitrogen dynamics can directly impact crop health and yields (Huang *et al.* 2004; Brass *et al.* 2008). The strategic management of sawdust application is therefore crucial to fully leverage its benefits while addressing the potential challenges associated with nitrogen immobilization and the overall nutritional status of plants (Rajor *et al.* 1996). By implementing effective management strategies, growers can improve soil health and boost plant productivity, thereby promoting sustainable plant growth practices over the long term.

Furthermore, the incorporation of sawdust into soil has been shown to stimulate saprotrophic fungal activity, which plays a vital role in nitrogen retention. This fungal activity is essential for minimizing nitrogen losses in arable soils, positioning sawdust as a valuable resource in the realm of sustainable agriculture (Rojas-Higuera *et al.* 2017). The multifaceted benefits of sawdust, ranging from enhancing soil health to reducing nitrogen loss, underscore its potential as an effective and sustainable amendment within agricultural systems, particularly when synergistically combined with other organic materials. This holistic approach not only supports plant growth but also contributes to the resilience and sustainability of agricultural ecosystems (Olayinka and Adebayo 1985).

The demand for medicinal and aromatic plants has surged dramatically in recent years, reflecting a growing awareness of their health benefits and therapeutic properties (Çiçek *et al.* 2023). Among these plants, lavender (*Lavandula* spp.) has emerged as a particularly valuable species, especially in Türkiye, where its cultivation has gained traction due to its straightforward growing requirements and eco-friendly characteristics (Yücedağ *et al.* 2024). Lavender encompasses several species, with three of the most commercially significant being L. *officinalis*, L. x *intermedia*, and L. *spica*. These species are predominantly native to the Mediterranean region and are recognized for their extensive applications in various industries, including cosmetics, aromatherapy, and pharmaceuticals (Kara 2023).

*Lavandula officinalis*, which is often referred to as medicinal lavender, is especially noteworthy. This perennial shrub is popular not only for its striking purple blooms—typically appearing between April and June—but also for its valuable essential oils that can be extracted from both its leaves and flowers. These oils are renowned for their calming and therapeutic qualities, making *L. officinalis* a staple in holistic health practices and natural remedies (Tahmineh *et al.* 2015). The increasing interest in such plants underscores a broader trend towards sustainable plant cultivation and natural wellness solutions, positioning lavender as a key player in the global market for medicinal and aromatic plants. As the global trade of medicinal and aromatic plants expands, lavender's role in this market is increasingly recognized for its economic potential and therapeutic applications (Crisan *et al.* 2023; Tripathi *et al.* 2017), and its versatility across sectors such as cosmetics, food, and medicine continues to drive research and innovation in lavender cultivation and utilization (Crisan *et al.* 2023; Öztaş *et al.* 2024).

The increasing acknowledgment of lavender's significance underscores the urgent necessity for comprehensive research focused on its production. This includes exploring various aspects such as economic viability, cost-effectiveness, and the development of sustainable growth media. By delving deeper into these areas, there is an opportunity to better understand how to optimize lavender cultivation while ensuring environmental responsibility and economic feasibility. Such studies will not only enhance the knowledge of lavender production but also contribute to the broader discourse on sustainable agricultural practices (Szekely-Varga *et al.* 2020) and their implications for the future of the industry. By integrating innovative cultivation methods and understanding the phytochemical profiles of lavender, researchers can unlock new opportunities for its use in health and wellness sectors (Aboud *et al.* 2020; Crisan *et al.* 2023).

Despite the increasing interest in sustainable horticultural practices, there has been a notable absence of research specifically examining the impact of Scots pine sawdust as a growth medium for lavender. This study aims to fill that gap by investigating the effects of Scots pine sawdust on various aspects of *L. officinalis*, commonly known as lavender, which is a popular ornamental plant both in Türkiye and globally. The primary objectives of this research include evaluating how Scots pine sawdust influences the overall quality and growth of lavender, as well as assessing key photosynthetic parameters and nutrient content within the plant. By conducting a series of controlled experiments, the study seeks to determine the optimal proportion of Scots pine sawdust that can be incorporated into the growth medium to enhance the development of robust and aesthetically pleasing ornamental lavender plants. Ultimately, the findings from this research will provide valuable insights for horticulturists and gardeners, guiding them in effectively using Scots pine sawdust as a sustainable growing medium, thus contributing to the cultivation of superior lavender specimens that thrive both in appearance and health. Researching the effects of Scots pine sawdust on lavender growth will also contribute to the understanding of sustainable practices in ornamental horticulture, promoting environmentally friendly cultivation methods. This study will address the need for innovative solutions in the ornamental horticulture industry by exploring sustainable practices that can enhance lavender production while minimizing environmental impact.

## EXPERIMENTAL

This study was conducted in the Research and Application Greenhouse of Çankırı Karatekin University (40°37'32" N, 33°36'30" E, 884 m a.s.l.). The average daytime temperature ranged between 30 and 35 °C, and relative humidity was approximately 65 to 70%. *L. officinalis* was used as the test plant. To prepare the base substrate, three parts peat were mixed with one part perlite (3:1, v/v), creating a medium with both water-holding capacity and improved aeration. The use of peat in this study aimed to provide a steady nutrient supply and high water retention (Korkmaz and Çiçek 2024). Perlite, an inert and porous volcanic material, was added to improve drainage and oxygen availability to plant roots, helping prevent root diseases associated with excessive moisture (Çiçek 2010). Eleven different growth media were formulated by adding various proportions of Scots pine (*Pinus sylvestris*) sawdust (ranging from 5% to 50% by volume) to this peat–perlite base mixture. The purpose of including Scots pine sawdust was to evaluate its potential as an environmentally friendly, cost-effective alternative substrate. Sawdust contributes organic matter, improves soil structure, and is widely available as a forestry byproduct. No basal fertilization was applied throughout the experiment, so that it would be possible to isolate the effects of the substrate compositions. The experiment was designed according to a completely randomized block design with five replications. Plants were grown in 4-liter pots for a period of twelve weeks.

### Physical and Chemical Properties of Substrates

Table 1 presents some physical and chemical properties of the peat and the sawdust used. In the experiment, pH and electrical conductivity (EC) of growing medium were determined according to Gabriels and Verdonck (1992), and the organic matter by Horneck *et al.* (1989). A total N analysis was carried out by the Kjeldahl method (Bremner 1965; Kacar 2009). Phosphorus, potassium, calcium, magnesium, iron, zinc, manganese, and copper contents of peat were found by a Perkin Elmer Optima 2100 brand Inductively Coupled Plasma – Optical Emission (ICP-OES) device in saturated medium extract (Kirven 1986; Kacar 2009). Phosphorus, potassium, calcium, magnesium, iron, zinc, and manganese contents in the extract obtained as a result of dry burning of sawdust were determined using a Perkin Elmer Optima 2100 brand ICP-OES device (Pratt 1965; Kirven 1986; Kacar 2009).

**Table 1.** Some Physical and Chemical Properties of the Peat and Scots Pine (*Pinus sylvestris* L.) Sawdust Used in the Study

| Parameter | Peat | Parameter | Sawdust |
|---|---|---|---|
| pH | 5.54 | pH | 6.12 |
| EC (dS $m^{-1}$) | 0.43 | EC (dS $m^{-1}$) | 1.07 |
| Organic material (%) | 93.00 | Organic material (%) | 58.00 |
| Total N (%) | 1.11 | -- | -- |
| Extractable P (mg $kg^{-1}$) | 0.28 | Total P (%) | 0.17 |
| Extractable K (mg $kg^{-1}$) | 15.00 | Total K (%) | 0.62 |
| Extractable Ca (mg $kg^{-1}$) | 182.00 | Total Ca (%) | 1.92 |
| Extractable Mg (mg $kg^{-1}$) | 22.00 | Total Mg (%) | 0.73 |
| Water-soluble Fe (mg $kg^{-1}$) | 0.15 | Total Fe (mg $kg^{-1}$) | 2.15 |
| Water-soluble Zn (mg $kg^{-1}$) | 0.30 | Total Zn (mg $kg^{-1}$) | 43.00 |
| Water-soluble Cu (mg $kg^{-1}$) | 0.48 | Total Cu (mg $kg^{-1}$) | 7.00 |
| Water-soluble Mn (mg $kg^{-1}$) | 0.59 | Total Mn (mg $kg^{-1}$) | 52.00 |

Note: (EC = Electrical Conductivity; OM = Organic Matter; N = Total Nitrogen; Extractable and water-soluble nutrients were determined using standard soil extraction protocols)

## Growth Parameters and Aesthetic Evaluation

Before harvest, plants were visually assessed for their aesthetic appearance, including overall form, flower abundance, vitality, and brightness. A five-member panel (including two academic staff, two graduate students in landscape architecture, and one ornamental plant producer) scored each plant from 1 to 10 with 1 being the worst and 10 being the best.

The crown width (CW, cm), flower number, and weight (g), plant height (cm), plant fresh, and dry weights (g) were measured according to Kütük *et al.* (1998) and Çiçek (2010). Plant height was determined by measuring the part of the plant from the growing medium surface to the highest point of the plant in each pot with a ruler. Crown width was measured by the projection diameter of the plant crown in the north-south and east-west directions and taking the average. The plant dry weight was determined by drying them in an air-circulated plant drying oven (65 to 70 °C) until they reached a constant weight and then weighing the dry plant samples on a precision scale without delay.

## Photosynthetic Pigment Analysis

A total of 10 mL of 90% v/v acetone were used to homogenize 250 mg of fresh leaf samples. The photosynthetic pigments' absorbance at 645, 663, and 470 nm was measured using a spectrophotometer (UV/VIS-1201, Shimadzu Corp., Kyoto, Japan). Arnon (1949) and Withman *et al.* (1971) served as the basis for the calculations of the concentrations of carotenoids (Car) and chlorophyll (Chl).

### Nutrient Content in Plant Tissues

Total nitrogen in plant tissues was determined using the Kjeldahl method. Phosphorus was analyzed *via* the vanadomolybdophosphoric yellow color method, potassium by flame photometry, and calcium, magnesium, iron, copper, zinc, and manganese *via* ICP-OES, following Kacar and Inal (2008).

### Statistical Analysis

The means of the characteristics studied were compared between the treatments using one-way variance analysis. Duncan's multiple range test was used for post-hoc comparisons when significant differences were detected ($p < 0.05$). Statistical analyses were performed using IBM SPSS Statistics 25 (IBM Corp., Armonk, NY, USA).

## RESULTS AND DISCUSSION

### Effects of Sawdust on Growth and Aesthetic Quality

Statistical analyses revealed significant differences in aesthetic appearance score, crown width, plant height, and plant fresh weight among the sawdust treatments ($p < 0.001$). The 25% sawdust treatment resulted in the highest values across all these parameters: aesthetic appearance score (9.7 ± 0.2), crown width (25.2 ± 0.3 cm), plant height (57.8 ± 0.3 cm), and plant fresh weight (59.0 ± 0.8 g). Compared to the control group, these values represented increases of 15.5%, 18.3%, 23%, and 30.7%, respectively (Table 2). These results suggest that moderate sawdust application enhances overall plant quality, possibly by improving root zone conditions such as aeration and microbial activity. Similar findings have been reported in sesame (Eifediyi *et al.* 2022), *Xanthosoma mafafa* (Iroegbu *et al.* 2020), and *Ribes nigrum* (Paunović *et al.* 2020), where moderate levels of sawdust improved plant height and biomass. Conversely, excessive sawdust amounts were associated with reduced growth in other species such as *Eucalyptus saligna* (Ashiono *et al.* 2017) and sugar beet (Kovacik *et al.* 2020), which supports the growth-depressive effect seen at 50% sawdust in our study. Although vegetative growth responded positively to moderate sawdust levels, no statistically significant differences were observed in flower number, flower weight, and plant dry weight ($p > 0.05$), suggesting that reproductive traits were less sensitive to changes in growth media (Table 2).

### Effects of Sawdust on Photosynthetic Pigments

Chlorophyll a and b contents exhibited a declining trend as sawdust concentration increased. Specifically, the 50% sawdust treatment showed an 18.5% reduction in chlorophyll a and a 23.5% reduction in chlorophyll b compared to the control. Similarly, total chlorophyll (Chl a + b) was reduced by 19.9% in the 50% treatment (Table 3). The highest values for Chl a (0.743 ± 0.010 mg/g FW), Chl b (0.322 ± 0.004 mg/g FW), and Chl a + b (1.065 ± 0.010 mg/g FW) were recorded at 15% sawdust. This indicates that low to moderate levels of sawdust can support or enhance photosynthetic pigment concentration, while higher levels may inhibit chlorophyll synthesis, potentially due to nutrient competition or microbial immobilization of nitrogen (Huang *et al.* 2004; Kovacik *et al.* 2020).

**Table 2.** Effects of Different Scots Pine (*Pinus sylvestris* L.) Sawdust Percentages on Visual Quality and Growth Parameters of *Lavandula officinalis*

| Treatment | AAS (1-10) | CW (cm) | NF | FW (g) | pH (cm) | PFW (g) | PDW (g) |
|---|---|---|---|---|---|---|---|
| Control | 8.4 ± 0.2cd | 21.3 ± 0.6d | 21.2 ± 1.4 | 3.1 ± 0.4 | 54.0 ± 0.9bcde | 45.2 ± 3.3b | 18.1 ± 1.7 |
| 5% Sawdust | 8.8 ± 0.2bc | 23.5 ± 0.8abc | 22.0 ± 1.4 | 3.3 ± 0.3 | 54.8 ± 0.6bcd | 54.8 ± 1.7a | 23.4 ± 3.4 |
| 10% Sawdust | 9.1 ± 0.2ab | 24.5 ± 0.6ab | 22.8 ± 1.2 | 3.4 ± 0.2 | 56.0 ± 0.5ab | 51.7 ± 2.1ab | 18.8 ± 1.9 |
| 15% Sawdust | 9.0 ± 0.1bc | 24.9 ± 0.7a | 23.0 ± 1.1 | 3.5 ± 0.2 | 57.4 ± 0.4a | 54.6 ± 1.4a | 21.1 ± 2.1 |
| 20% Sawdust | 9.4 ± 0.2ab | 25.0 ± 0.5a | 23.4 ± 0.8 | 3.7 ± 0.2 | 57.2 ± 0.8a | 56.0 ± 2.5a | 21.7 ± 2.0 |
| 25% Sawdust | 9.7 ± 0.2a | 25.2 ± 0.3a | 24.8 ± 1.2 | 3.6 ± 0.2 | 57.8 ± 0.3a | 59.0 ± 0.8a | 23.2 ± 1.5 |
| 30% Sawdust | 9.7 ± 0.2a | 24.7 ± 0.4a | 22.2 ± 1.4 | 3.3 ± 0.4 | 55.0 ± 0.5bc | 55.1 ± 3.0a | 24.9 ± 1.3 |
| 35% Sawdust | 9.1 ± 0.2ab | 22.8 ± 0.5bcd | 22.4 ± 1.8 | 3.1 ± 0.4 | 52.7 ± 0.7de | 54.2 ± 3.1a | 22.4 ± 3.7 |
| 40% Sawdust | 9.0 ± 0.2bc | 22.0 ± 0.8cd | 21.0 ± 1.0 | 2.8 ± 0.3 | 53.9 ± 1.0bcde | 45.9 ± 3.1b | 17.7 ± 2.8 |
| 45% Sawdust | 8.4 ± 0.3cd | 22.0 ± 0.8cd | 20.4 ± 2.3 | 2.9 ± 0.5 | 53.8 ± 0.8cde | 46.3 ± 2.7b | 16.3 ± 1.2 |
| 50% Sawdust | 8.1 ± 0.2cd | 21.8 ± 0.5cd | 19.4 ± 2.0 | 2.8 ± 0.4 | 51.9 ± 0.5e | 46.0 ± 1.5b | 19.8 ± 1.9 |
| Mean | 9.0 ± 0.1 | 23.4 ± 0.3 | 22.1 ± 0.4 | 3.2 ± 0.1 | 55.0 ± 0.3 | 51.7 ± 0.9 | 20.7 ± 0.7 |
| Min-Max | 7.6 to 10.0 | 19.9 to 26.8 | 13.0 to 29.0 | 1.2 to 4.2 | 50.1 to 58.7 | 36.5 to 63.5 | 12.1 to 36.0 |
| P | 0.000 | 0.000 | 0.418 | 0.541 | 0.000 | 0.000 | 0.201 |

Note: (AAS = Aesthetic Appearance Score; CW = Crown Width; NF = Number of Flowers; FW = Flower Weight; PH = Plant Height; PFW = Plant Fresh Weight; PDW = Plant Dry Weight. Values represent mean ± standard deviation. Different letters indicate significant differences according to Duncan's test ($p < 0.05$).)

Carotenoid (Car) levels also tended to decrease with increasing sawdust content, with a 10.5% decline at 50% sawdust. However, the Chl a + b / Car ratio did not show statistically significant differences across treatments ($p = 0.113$) (Table 3), indicating a relatively stable pigment balance despite total pigment reduction.

## Effects of Sawdust on Nutrient Content

One of the most unexpected findings of the study was the significant increase in total nitrogen content as sawdust concentration increased. The highest nitrogen content (2.49 ± 0.14%) was found in the 50% sawdust treatment, representing a 76.6% increase over the control (Table 4). This result is surprising, considering that sawdust is often associated with nitrogen immobilization due to its high carbon-to-nitrogen (C:N) ratio (Huang *et al.* 2004). However, it is hypothesized that the sawdust used in this study may have included bark, cambial tissue, or young xylem, which are known to contain higher levels of nitrogen than mature wood (Camargo *et al.* 2014; Ninkuu *et al.* 2023). Additionally, the combination with peat and perlite likely improved aeration and microbial activity, enabling controlled decomposition and mineralization of organic nitrogen.

**Table 3.** Effects of Different Scots Pine (*Pinus sylvestris* L.) Sawdust Percentages on Chlorophyll and Carotenoid Content in *Lavandula officinalis*

| Treatment | Chl *a* (mg g$^{-1}$ FW) | Chl *b* (mg g$^{-1}$ FW) | Chl *a+b* (mg g$^{-1}$ FW) | Car (mg g$^{-1}$ FW) | Chl *a+b* / Car |
|---|---|---|---|---|---|
| Control | 0.736 ± 0.028ab | 0.299 ± 0.007bc | 1.035 ± 0.028ab | 0.220 ± 0.005a | 4.72 ± 0.19 |
| 5% Sawdust | 0.738 ± 0.008ab | 0.309 ± 0.008ab | 1.047 ± 0.008ab | 0.234 ± 0.007a | 4.49 ± 0.12 |
| 10% Sawdust | 0.741 ± 0.009ab | 0.311 ± 0.008ab | 1.052 ± 0.015a | 0.224 ± 0.005a | 4.70 ± 0.10 |
| 15% Sawdust | 0.743 ± 0.010a | 0.322 ± 0.004a | 1.065 ± 0.010a | 0.230 ± 0.004a | 4.64 ± 0.12 |
| 20% Sawdust | 0.735 ± 0.004ab | 0.312 ± 0.004ab | 1.047 ± 0.007ab | 0.227 ± 0.007a | 4.63 ± 0.14 |
| 25% Sawdust | 0.734 ± 0.018ab | 0.310 ± 0.006ab | 1.044 ± 0.024ab | 0.231 ± 0.005a | 4.53 ± 0.14 |
| 30% Sawdust | 0.711 ± 0.008abc | 0.289 ± 0.003cd | 0.999 ± 0.010bc | 0.222 ± 0.004a | 4.51 ± 0.07 |
| 35% Sawdust | 0.700 ± 0.010bc | 0.273 ± 0.006de | 0.973 ± 0.015cd | 0.217 ± 0.007a | 4.49 ± 0.13 |
| 40% Sawdust | 0.684 ± 0.008c | 0.264 ± 0.006e | 0.948 ± 0.009d | 0.197 ± 0.003b | 4.81 ± 0.08 |
| 45% Sawdust | 0.639 ± 0.015d | 0.246 ± 0.002f | 0.885 ± 0.017e | 0.195 ± 0.004b | 4.55 ± 0.10 |
| 50% Sawdust | 0.600 ± 0.005e | 0.229 ± 0.005g | 0.829 ± 0.009f | 0.197 ± 0.004b | 4.21 ± 0.12 |
| Mean | 0.706 ± 0.007 | 0.288 ± 0.004 | 0.993 ± 0.011 | 0.218 ± 0.002 | 4.57 ± 0.04 |
| Min-Max | 0.590 to 0.820 | 0.210 to 0.330 | 0.800 to 1.130 | 0.180 to 0.260 | 3.99 to 5.18 |
| P | 0.000 | 0.000 | 0.000 | 0.000 | 0.113 |

Note: Chl a = Chlorophyll a; Chl b = Chlorophyll b; Chl a+b = Total Chlorophyll; Car = Carotenoids; FW = Fresh Weight. Values represent mean ± standard deviation. Different letters within a column indicate significant differences according to Duncan’s multiple range test ($p < 0.05$).

Phosphorus levels remained stable across treatments ($p = 0.736$), with only minor fluctuations, aligning with previous findings on P stability in organic-rich substrates. Similarly, magnesium content showed little variation and peaked slightly at 50% sawdust (0.51 ± 0.01%) (Table 4). Calcium content increased with sawdust up to the 25% treatment, reaching 2.67 ± 0.09%, which was 48.3% higher than the control. This could be attributed to improved root development or microbial release of Ca from the organic matrix (Table 4). In contrast, micronutrients such as iron, copper, and zinc decreased as sawdust levels increased. Iron content dropped 36.3%, copper 50.8%, and zinc 40.2% in the 50% sawdust treatment compared to control (Table 4). These declines could be the result of competition between plants and microbes for micronutrients, as well as potential binding of metals in organic complexes or changes in pH and redox conditions. Manganese exhibited a more variable pattern, peaking slightly at 40% sawdust and declining sharply at higher levels (Table 4). This suggests species-specific and concentration-dependent responses of micronutrients to organic amendments.

**Table 4.** Effects of Different Scots Pine (*Pinus sylvestris* L.) Sawdust Percentages on Macro- and Micronutrient Content of *Lavandula officinalis* Shoots

| Treatment | N (%) | P (%) | Ca (%) | Mg (%) | Fe (mg kg$^{-1}$) | Mn (mg kg$^{-1}$) | Cu (mg kg$^{-1}$) | Zn (mg kg$^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| Control | 1.41 ± 0.02e | 0.27 ± 0.02 | 1.80 ± 0.09c | 0.42 ± 0.03 | 367.60 ± 22.28a | 61.60 ± 1.86a | 22.80 ± 1.16a | 38.00 ± 1.23a |
| 5% Sawdust | 1.59 ± 0.02e | 0.30 ± 0.01 | 2.07 ± 0.12bc | 0.47 ± 0.01 | 345.80 ± 16.60ab | 54.80 ± 2.33b | 19.60 ± 0.93b | 34.00 ± 1.30b |
| 10% Sawdust | 1.54 ± 0.05e | 0.26 ± 0.03 | 2.16 ± 0.10b | 0.45 ± 0.02 | 351.20 ± 19.65ab | 49.20 ± 2.15b | 18.40 ± 0.81b | 30.00 ± 2.00c |
| 15% Sawdust | 1.68 ± 0.06de | 0.28 ± 0.02 | 2.12 ± 0.07bc | 0.46 ± 0.03 | 323.20 ± 9.65bc | 43.00 ± 1.30c | 18.60 ± 1.17b | 28.00 ± 1.52cd |
| 20% Sawdust | 1.91 ± 0.11cd | 0.26 ± 0.02 | 2.30 ± 0.13b | 0.50 ± 0.01 | 300.40 ± 16.85cd | 41.00 ± 1.41c | 17.40 ± 1.33bc | 26.80 ± 0.86cd |
| 25% Sawdust | 1.98 ± 0.12bc | 0.25 ± 0.02 | 2.67 ± 0.09a | 0.48 ± 0.03 | 289.00 ± 11.80cd | 38.20 ± 1.07cd | 16.60 ± 1.03bcd | 29.60 ± 1.21c |
| 30% Sawdust | 2.26 ± 0.10ab | 0.24 ± 0.01 | 2.68 ± 0.16a | 0.49 ± 0.02 | 283.20 ± 11.20cd | 37.40 ± 1.33cd | 16.40 ± 1.63bcde | 25.60 ± 1.08de |
| 35% Sawdust | 2.22 ± 0.10ab | 0.25 ± 0.01 | 2.85 ± 0.07a | 0.48 ± 0.05 | 261.80 ± 9.54de | 32.40 ± 3.31de | 14.20 ± 0.58cdef | 24.40 ± 1.47de |
| 40% Sawdust | 2.25 ± 0.12ab | 0.28 ± 0.02 | 2.71 ± 0.11a | 0.47 ± 0.02 | 239.60 ± 6.70e | 60.60 ± 1.47e | 13.80 ± 0.86def | 22.60 ± 0.75e |
| 45% Sawdust | 2.46 ± 0.11a | 0.26 ± 0.02 | 2.85 ± 0.10a | 0.46 ± 0.03 | 228.00 ± 6.47e | 27.20 ± 1.77e | 13.20 ± 0.86ef | 21.80 ± 1.07e |
| 50% Sawdust | 2.49 ± 0.14a | 0.27 ± 0.03 | 2.83 ± 0.14a | 0.51 ± 0.01 | 234.20 ± 8.52e | 27.80 ± 2.48e | 11.20 ± 0.58f | 22.60 ± 0.93e |
| Mean | 1.98 ± 0.06 | 0.27 ± 0.01 | 2.46 ± 0.06 | 0.47 ± 0.08 | 293.09 ± 7.40 | 40.29 ± 1.55 | 16.56 ± 0.51 | 27.58 ± 0.74 |
| Min-Max | 1.36 to 2.85 | 0.20 to 0.37 | 1.56 to 3.15 | 0.33 to 0.58 | 208.00 to 412.00 | 22.00 to 67.00 | 10.00 to 26.00 | 19.00 to 42.00 |
| P | 0.000 | 0.736 | 0.000 | 0.563 | 0.000 | 0.000 | 0.000 | 0.000 |

Note: (N = Total Nitrogen; P = Phosphorus; Ca = Calcium; Mg = Magnesium; Fe = Iron; Mn = Manganese; Cu = Copper; Zn = Zinc. Values are expressed as mean ± standard deviation. Different letters within a column indicate significant differences according to Duncan's multiple range test ($p < 0.05$).)

## CONCLUSIONS

1. This study aimed to investigate the effects of incorporating Scots pine (*Pinus sylvestris*) sawdust into peat-based growing media on the growth, visual quality, photosynthetic capacity, and nutrient content of *Lavandula officinalis*. The broader objective was to evaluate the potential of sawdust—a readily available forestry byproduct—as a sustainable alternative to conventional substrates such as peat. The findings clearly demonstrated that moderate inclusion of sawdust (particularly at 25% v/v) significantly

enhanced plant height, crown width, fresh weight, and aesthetic appearance without compromising flower development. Photosynthetic pigment concentrations and calcium uptake were also optimized at this level, while excessive sawdust (≥ 40%) led to reduced chlorophyll and micronutrient levels.

2. Contrary to initial expectations, nitrogen content increased with higher sawdust levels. This surprising result may be explained by the presence of young woody tissues in sawdust and improved mineralization conditions within the peat-perlite matrix. These insights underscore the complex interactions between organic substrates, microbial activity, and nutrient dynamics.
3. From a practical perspective, this research identified 25% sawdust as the optimal ratio for supporting both physiological performance and ornamental value in *L. officinalis*. Importantly, it highlighted that sawdust—when properly combined with other media—can serve as a viable, cost-effective, and eco-friendly substrate component.
4. This study makes a novel contribution to sustainable horticulture by being the first to evaluate Scots pine sawdust as a growing medium component for lavender cultivation. It provides experimental evidence on how varying levels of sawdust affect plant physiology and nutrient status, filling a critical gap in the literature on lavender production. Moreover, the research supports the integration of circular bioeconomy principles into ornamental plant production by offering a practical pathway for repurposing forestry residues. These findings may inform future media formulation strategies for a wide range of aromatic and ornamental plants, contributing to resource-efficient, climate-resilient horticultural systems.

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Article submitted: January 11, 2025; Peer review completed: March 1, 2025; Revised version received and accepted: May 15, 2025; Published: May 28, 2025.
DOI: 10.15376/biores.20.3.5801-5813

ERRATUM: January 23, 2026, Table 1 has been reorganized with different headings but values remain the same